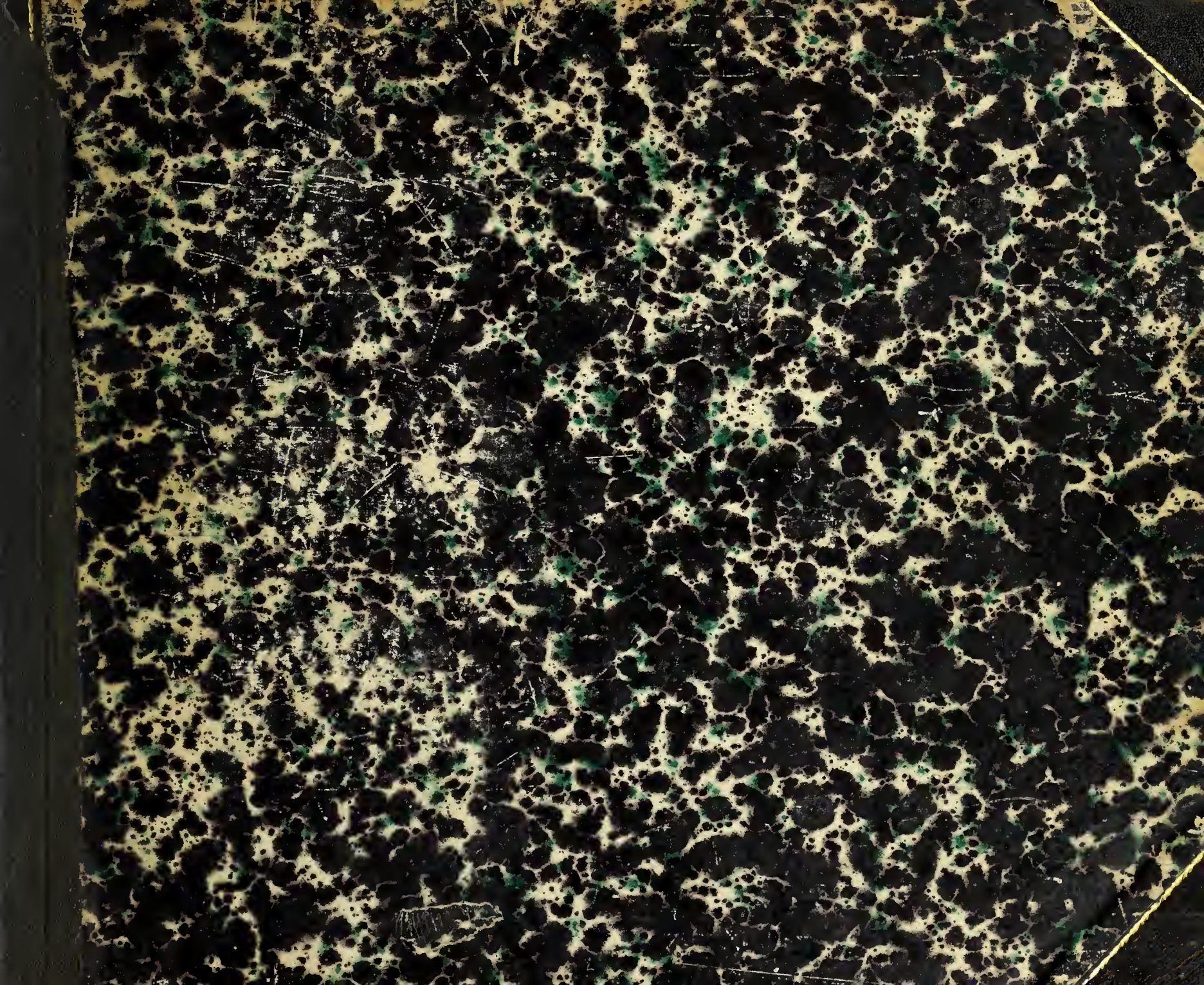

No. 9491

DEPARTMENT OF

1883 M3

LIBRARY OF

University of Illinois.

Books are not to be taken from the Library Room.

1883
M3

Index to Theses

Author	Subject	Degree
Sondericker, P.	Relations of Chem. Comp. to Phy. Prop. of Steel	Degree of M.S.
Beardsley, Henry M.	Abraham Lincoln in our own County	Degree of M.E.
Renouard, George F.	School Government	Degree of M.E.
Brown, K.L.	Compulsory Education	Degree of M.E.
Reynolds, A.S.	Geology of Arkansas	Degree of M.S.

Digitized by the Internet Archive
in 2016

https://archive.org/details/thesisonrelation00sond

— Thesis —

On the Relations of the Chemical Composition to
the Physical Properties of Steel.

Written by

L. Sonderecker

For a Master's Degree in the Course of Civil Engineering

Ills. Industrial Univ.

— 1883 —

15e3
M3

Thesis.

On the relation between the Chemical composition and physical properties of steel, including a discussion of the experiments made by the U.S. Board for testing iron and steel.

The subject of the relation between the Chemical composition and physical properties of steel is one which is constantly growing in importance with Engineers and steel manufacturers. The present knowledge upon this subject is very indefinite, owing no doubt largely to the great effect which the process of manufacture has upon the physical properties of the metal. But with an increasing knowledge among manufacturers of the best methods of treating the metal, steel having a given Chemical composition will possess more uniform physical properties, then a knowledge of the Chemical composition will increase in value - the properties of each ingredient will be more definitely known. Indeed is not the great importance given by engineers to physical tests, as compared with Chemical tests due, in some degree to the great variations in the quality of the metal caused by the different methods of treatment by the manufacturer, and when when the methods

UIUC

of treatment become more common it seems probable that Chemical tests will increase in importance.

It may be said, that Chemical tests are useful only to the manufacturer. This does not appear to me to be true. Chemical tests in connection with physical tests are necessary for a complete understanding of the character of the metal. Two bars of steel may have the same strength, Elastic limit, ductility &c. and yet differ in value for many purposes. What physical tests will determine the metal best fitted for steel rails? The only certain test at present seems to be the test of actual use. But this would be a very tedious method of making the test. Could not a thorough knowledge of the Chemical composition greatly enlighten us in this respect. It would seem so and such tests have been undertaken.

Again, how do we know that two steels having different Chemical composition but the same physical properties will equally withstand the repeated shocks and vibrations to which Rail Road Bridges are subject. May not a difference in Chemical Composition make a difference in their power to withstand such shocks. This seems at least possible. It would be im-

practicable to subject a bridge steel to the repeated shocks and vibrations to which it is subject in practice. One must rely on less expensive test, surely a physical and chemical test will define their applicability for a special purpose better than physical tests alone.

Again, an engineer may, for some special purpose desire a steel having properties different from any steel in the market, for example in instance of the Chrome steel used in the St Louis Bridge. A knowledge of the properties of the Chemical ingredients of steel in such a case would be of value to the engineer enabling him to indicate to the manufacturer the Chemical composition which would probably produce steel having the required properties.

These are some of the reasons why it seems to me desirable that the engineer posses a knowledge of the effect of the Chemical ingredients of steel as well as a knowledge of their physical properties.

Explanation. I do not make a record here of the experiments used in connection with this investigation because they can be readily obtained from the reports of the U.S. Board on testing iron & steel. In carrying on the investigation I arranged the separate results for each physical test, in the

three experiments corresponding to a given Chemical analysis. If the physical tests in the three experiments were uniform, & gave quality importance to such than I did to those which differed greatly among themselves. The numbers refer to the corresponding numbers in the record of the experiments.

In the discussion of a series of experiments similar to those under consideration, the question of what method to follow is an important one. Three general methods have come under my notice (1) Method of least squares, (2) By means of general averages of a number of experiments. (3) By inspection or by a comparison of the individual results. The question arises as to which of these methods will probably give the best results.

I Method of least squares. At the commencement of my investigation I employed this method, but reasons independent of the results obtained convinced me that the method was incorrect as employed. I employed this method as follows:— Selecting such analyses as differed only in the percentages of a few of the elements present, I formed a series of equations, between the differences in their Chemical composition and the corresponding differences in their physical properties. Thus if the difference in the percents of iron

present, in the two cases to be represented by a, & silicon by b, & Mg. by c &c, and the corresponding differences in breaking strength (for instance) by T, I formed the equation $aC + bSi + cMg = T$. in which C stands for carbon Si, silicon &c. Forming a number of such equations, I reduced them by the method of least Squares thus determining the effect of 1% of each of these substances on the breaking strength. Although the results agreed pretty well with those determined by inspection of the same data, still the method was unsatisfactory to me for the reasons which follow.

The method of least Squares, the equations being put in a form similar to the above, would give correct results, first if the effect of Silicon, Carbon &c was constant, i.e. if the effect of 1% of Silicon, for instance, on the physical properties, was the same no matter whether it existed in the metal in large or small amounts. Second, if the effect of each element was independent of the presence of other elements. 3rd if the steel was manufactured by the same process and under the same conditions.

I. The solution by method of least squares, also by method of (mean averages) assumes that the effect of an element is constant for varying pro-

portions of the ingredient. This we think is not true. The addition of 1% of C. to low steel produces a greater change in its physical properties, than an addition of the same amount of C. to high steel, and even produces the opposite effect, i.e. reduces the strength when the percent of C. becomes large (exceeds 1.3% to 1.5%). The results of my investigations sustain me in the conclusion that the effect of an element on the physical properties of steel is not constant

II The method of least squares assumes that each element exerts its influence independent of the presence of other elements: i.e. that Si. will produce the same effect whether Mg. is present in large or in small amounts or not at all. The results of my investigations show also that this assumption is not true.

The 3rd reason (differences in manufacture) of course affects my method of discussion. And lastly the large probable error in the determinations worked by method of least Squares indicates its inapplicability.

The above reasons appear to me sufficient to condemn the method of least squares, and the method of general averages in this discussion. There

might possibly be cases so favorable that the above considerations would produce little error in the results. These reasons which I at first considered as mere probabilities were confirmed by examination of the data at hand, and afterwards by the testimony of others, so that they appear to me conclusive.

Dr Raymond of Troy N.Y. in his discussion of the experiments conducted by Dr Dudley on the 60 lb rails employed the method of least squares, not so much it appears to deduce correct results as to test Dr Dudley's results. For as admitted by Dr Raymond, the method of least squares and the method of general averages are based upon the same assumptions, one of these assumptions being "that the loss of metal (the property under discussion) depends upon the proportions of the various constituents of the rail & that the amount of loss is affected by each constituent in a fixed ratio." ~~and he adds~~, "This assumption I contend is false & the very different results obtained by Dr. Raymond & Dr. Dudley confirm me in this. Dr Raymond's Equations were of the form $I + cC + pP + sS + mM = R$, in which "I" is an unknown quantity depending on the iron and assumed to be constant for all the rails. C, P, S, & M are the experimentally determined quantities of Carbon, Phosphorus,

Silicon and Manganese, & R, is the experimentally determined error per million tons. C. P. S. M are unknown coefficients to be determined by solution."
"In other words it is assumed that the difference in wear is proportional to the differences in C., Ph. Si. & Mg. & that the effect of a change in the amount of either is independent of the amount of the rest within the experimental limits of the problem." Of course we would not expect the same results to be obtained by the two methods, because the method of averages is not strictly mathematical but the results should practically agree with each other & we see that they do not. The results of the discussion by the method of least squares as stated by Dr Raymond were as follows. "Si, though a hundred increases the wearing capacity, Mg. seems to be neutral behaving like so much iron." The results agreeing with Dr Dudley only as respects the effect of Phos. & Carbon. This difference of conclusions arrived at by methods based upon the same assumptions indicates that the assumptions are incorrect. Prof. Akerman. (See Jour of Inst) says "If the iron and steel does not only contain Carbon & Mg. but also Phos. Si. & Sulphur the Mg. to a great extent can neutralize, not only the effect of red shortness caused by sulphur but also the tendency of the iron and steel to become burnt or

brittle caused by the Phos. and Si. Thus brittleness can be as well increased as decreased by the presence of Mg.". C. P. Sandberg remarks on the same subject "the amount of Mg. .35% might well be doubled in order to lessen the other 'deadly sins of impurities'." The same idea that the effect of an element is modified by the presence of others is referred to by Tom Sellers. "It has been found that larger percents of Phos. may be used provided that corresponding changes in the chemical composition be made to accord therewith. My conclusion that Phos. is more deleterious to high than to low steel is confirmed in a general way by the following; "When Carbon is present in quantity with Phos., Si, Mg., & Sulphur, it vitalizes and makes more active all the bad qualities of these elements. My own conclusions arrived at by a careful examination of the data at hand also confirms me in the above reasons as do the quotations just given.

Thus we conclude that the Method of least squares & the method of general averages as employed above will probably give incorrect results & should not therefore be employed in this discussion. The only safe way of carrying on such an investigation seems to be by a careful painstaking study of each individual experiment, comparing each with the others, & noting their differences in

chemical composition and the corresponding differences in physical properties, & the problem becomes to determine the effect of each in the presence of varying quantities of the others. With this problem in view I proceeded to determine the effects of the different elements found in steel from the experiments of the U.S. Board on testing iron & steel. I will give in connection with the results of this investigation some of the comparisons which led me to my conclusions. Then in connection with my own conclusions I will give the conclusions of others as found in papers & discussions on this subject.

Carbon.

526-528 Very similar in composition with the exception of carbon, carbon between .677% & .830% increases strength & decreases ductility.

1070-1071 Carbon between .850% & .980% increases strength & decreases ductility.

1072-1073. Carbon between .980% & 1.060% does not alter strength.

1072-1073-1074-1075-1076 shows an increase of strength with increased carbon up to 1.25% although this increased strength is no doubt partly due to increased amounts of Si. & Mg.

A careful comparison of a list of experiments pp 590-602 U.S. tests indicates that steel (in this case tool steel) decreases in both breaking strength & ductility.

when Carbon is above .1%. The comparison was made by taking the results of breaking strength for original section for fractured section in order + comparing with the corresponding % of Carbon. From this I would conclude that Carbon increases the breaking strength of steel, up to .8% at least. For know + all the experiments show that the effect of Carbon, in any amount is to lessen ductility.

Reynaud in his work upon iron + Steel says with regard to Carbon. "There is also in steel a limit to the % of carbon beyond which the tensile strength again decreases, so that the characteristics of the material approach more nearly to cast iron. The position of this limit depends likewise upon the presence of other elements." Knut Styffe gives the % of Carbon corresponding to maximum strength of steel as .8% for puddled steel + 1.2% for Bessemer steel. Karsden gives 1% to 1.5% for greatest strength.

Silicon.

1524-1525-1526-1527. A comparison of these respts. indicates that Si. up to .135% in steel containing .6% to .7% Carbon with small amounts of Mg. increases strength considerably + does not decrease ductility. The ductility of 1524 is no doubt largely due to its higher % of Mg.

1528-1070. Si. from .130% to .230% & Mg from .046% to .191% increases strength greatly, the variation in ductility is slight; the variations in the individual experiments under each number being greater than the difference in ductility of the two numbers

1529-1530-1531-1532. These four steels are very uniform in composition, the varying constituents are tabulated below with elongation and breaking strength.

No. of Exp't.	Car.	Si.	Elong.	Break. Stren.
1529	.908%	.141%	11.06	120275
1531	.966	.153	10.83	118156
1532	.946	.162	10.50	117993
1530	.927	.187	9.97	123697

These four experiments indicate that as the Si. increases the ductility diminishes regularly The effect upon the tensile strength is not perceptible. From this comparison we draw the conclusion that Si. above .140% in high steel in connection with very small amounts of Mg. decreases the ductility.

1531-1571. Si. from .153% to .225% and Mg. from .035 to .213% in high steel increases tensile strength considerably but decreases ductility.

No. of Exp't.	Car.	Si.	Elong.	Break. St.
1533	1.024%	.173%	10.33%	116000
1534	1.079	.096	7.25	110000
1535	1.112	.190	9.31	120000

The percent of Mg. in these three exp'ts. is small. The indications are clear. Si between .1% and .2% in high steel in connection with small amounts of Mg. increases both

strength and ductility considerably.

1053-1056. By reference to each separate experiment under each number we see that the ductility varies more in each set than the means. Thus.

	1053	1056
(1)	16.00%	4.91%
(2)	14.33%	16.92
(3)	13.67	16.17

so that no reliable result can be arrived at as far as it is concerned. Both experiments are uniform and the results go to show that Si. .213% + Mg .073% produce a stronger high steel, than Si .140% and Mg .101% + but slight variation in ductility. The greater ductility of 1056 can be accounted for by its higher percent of Mg. So that Si up to .2% is beneficial to high steel not containing over .1% of Mg.

1069-1070. Si. from .170% to .233% in .8 Carbon steel increases strength but decreases ductility, in presence of .190% Mg.

1071-1072 Si from .157% to .225% in high steel containing over .2% Mg. increases strength but decreases ductility. although it is probable that the Mg. in 1072 aids to increase its ductility

Conclusions. These conclusions only refer to high steel.

I Silicon in high steel up to .2% at least in connection with Mg. not over .1% increases strength + & does not affect ductility injuriously. or in these

proportions it is beneficial to high C steel. The only comparison which contradicts this conclusion is Ives 1529-1530 oc. but the variations in amounts of Si. present in this case is comparatively small so that the effect may be due to other causes.

II. Si. up to .2% in high steel in connection with large amounts of Mn. increases the strength but decreases the ductility. (other data seem to indicate that it does not decrease duct.)

A rapid examination of Dr Dudley's data indicates that Si. in mild steel for rails increases strength but does not increase ductility. The result may be different known for low steel of different Chemical composition.

The U.S. Testing Board says on this element, - that no ingredient of steel is less understood than Silicon "The managers of the Terre Noir works in France who have been notably successful in their steel manufacture believe that Si. up to a few tenths does not decrease the tenacity or ductility of steel, and it is true that good steels are made by various processes with as much as .2% of Silicon. It is believed by the Terre Noir managers that Silica is the cause of the bad effects usually attributed to Silicon.

Weyrauch says. "Silicon according to Landberg of Sweden & others exerts an influence similar to Carbon. Haswell considers it to neutralize to a certain extent the bad effects

of Phosphorus.

Manganese

1523-1067. Mg. up to .140% with .1% Silicon without diminishing the strength perceptably increases the ductility of .450 Carbon steel. The greater tensile strength of 1067 being accounted for by its larger % of Si.

1526-1055. Very similar in composition with the exception of Mg. and Copper. We know that copper is detrimental so that this comparison shows the effect of Mg. up to .140% with .130% of Si. in .7 Carbon steel is to increase ductility. The effect upon breaking strength is not perceptable.

1528-1069. A very good comparison. The greater amount of Si. in 1069 would increase its strength so that the experiments show that Mg. from .046% to .182% with .160% Si. in steel containing .840 C. increases ductility & does not decrease strength.

1528-1070. Mg. from .046% to .191% & Si. from .134% to .233% in steel containing .850% C. increases strength & decreases ductility. The effect of each substance cannot be determined here.

1529-1058 Mg. from .036% to .108% with .150% Si. in steel containing .9% C.

increases ductility largely & ~~decreases~~ does not increase breaking strength.

1530-1054. Same conclusion, as above Mg. from .031% to .155% with .190% Si in 9 C. steel increases ductility largely & decreases breaking strength.

1059. The low tensile strength of this steel is not accounted for by its chemical composition. The decided effect of the Mg. can be seen from the table below.

No.	Si	Car.	Mg.	Elong.	Break. St.
1530	.187	.927	.031	9.97	.123697.
1054	196	.886	185	17.44	156205.

1530-1072 Although the greater amount of Carbon in 1072 tends to increase the brittleness, the greater amt. of Mg. present increases the ductility. The effect of the Mg. on tensile strength is not so apparent. Mg. up to .245% with .180% Si. increases the ductility of the metal.

1531-(1056, 1058, 1059). indicates the that Mg. from .035% to .1% with .50% Si. in high steel increases ductility but decreases strength, however experiments 1058 & 1059 are unsatisfactory, being variable in physical properties & showing a weakness which their chemical composition does not account for.

1531-1071 Mg. from .035% to .213% & Si. from .153% to .225% in steel containing 950 C. increases strength & decreases ductility.

1531-1072. Mg. from .335% to .245% with .150% Si. in .980 C. Steel increases strength slightly but does not increase ductility. Mg. in this case seems to change the character of the steel very little

1533-1072. In 1.% C. steel, Mg. from .340% to .240% with .160% Si. increases strength somewhat but does not alter ductility

1535-1074 Mg. in 1.1% C steel up to .269/.282% increases strength and also ductility in presence of .190% Si.

1535-1075. Mg. in 1.1% C. steel with .2% Si. up to .282% increases strength and ductility.

No.	Si.	C.	Mg.	Elong.	Break. St.
1536	.114	1.186	.132	6.36	119514
1075	.204	1.142	.282	10.15	129443

These two experiments show that large amounts of Si. & Mg. are valuable ingredients in high steel increasing both strength & ductility largely. The effect of the Mg. here is clearly to increase the ductility of the metal.

No.	Si.	C.	Mg.	Elong.	Break. St.
1053	.213	.973	.043	14.67	103000
1054	.196	.886	.185	17.44	106000

Mg. in this case increases strength & ductility of steel. The exp. when compared with others that Mg. in small amounts produces a greater effect proportionally in the composition of steel than it does in larger amounts.

1053-(1071+1072) Mg. from .073% to .240% in .970% C. steel in connection with .2% Si. increases strength but not ductility, rather decreases ductility.

1056-1072. Mg. from .1% to .225% in .98% C. steel with .160% Si. increases strength but decreases ductility

1071+1072. The Si. in this experiment appears to affect the steel more than the Mg.

Out of a set of 19 pairs of experiments which gave direct evident on the question of the effect of Mg. on steel 13 indicated an increased ductility due to an increase in the amt. of Mg. present. & the remaining 6 indicated the opposite. But each of these 6 exp's included exp's No. 1071+1072 which have a small ductility, so that we conclude from an examination of this table as well as from the above comparisons that in general. I. In high steel containing from .8% to 1.2% Carbon. Mg. to .280% in connection with Si. from .1% to .225% increases the ductility of the metal. II. With regard to the effect of Mg. upon strength, the effect of Si. upon strength is so great that it is difficult to determine what part of the strength is due to the Mg. present. Of the 19 comparisons 13 show an increase in strength & in several cases where the % of Si. is diminished. Of the 6 comparisons which show

a decreased strength, it have a smaller amount of Si. to account for it, so that we may safely conclude that Mg. up to .280% in high steel in connection with Si. up to .2% does not diminish its tensile strength. Thus it appears that Mg. up to .280% in connection with Si. up to .2% is beneficial to high steel. In addition to these general conclusions it seems probable, 1) that the higher the percent of Carbon in the steel the more Mg. it will take without detriment to its physical properties. (2) In high steel with considerable (.15%-.2%) of Si. present the addition of Mg. from small amounts at first increases the ductility rapidly & as the % of Mg. increases, less rapidly until a pt. is reached when a further addition of Mg. decreases the ductility. These two conclusions are merely suggested from the exps. not proved.

The percent of Hco Si. vary so little that I cannot from these exps. determine how the presence of varying quantities of Si. affects the action of the Mg.

An examination of Dr Dudley's experiments show that in the mild steel containing from .2% to .5% of Carbon, employed in the manufacture of steel rails Mg. increases the ductility of the steel up to .7%. These conclusions with

respect to Mg are only reliable within the limits of the experiments; that is in high steel between 0 & .28% & in the mild steel for rails to .7% or .8%.

The U.S. Board for testing steel says "Mg. seems to toughen steel & to make it cast sound. Its hardening effect up to .2% or .3% is slight."

Dr Dudley recommends for steel rails the following composition:- Phos. - not above .1%, Si. not above .04%, C. between .25% & .35%, Mg. between .3% & .4%. These recommendations commend themselves to my judgment formed from an examination of his data, very well with the exception of Mg. I think the experiments indicate that Mg. may exist as high as .7% without producing any deleterious effect, on the contrary being beneficial. From the rapid examination I have given to the data it appears that Mg. from .4% to .7% would produce a better steel than the composition recommended. I refer to the effect upon strength & ductility, not upon wearing power.

R. W. Hunt in Jour. Frank. Inst. says with regard to Mg. "The rail makers both in this country & England are now making steel containing more Mg. than formerly. These rails are going out of the mills

apparently better and sounder than those formerly made" this is confirmed by two tested specimens presented by Mr Hunt & said to be good rails. They had the following composition.

	C.	Ph.	Si.	Mg.
I.	.410	.050	.086	.942
II.	.380	.058	.082	.840

This will be seen to agree with my conclusion that a higher percent of Mg. should be allowed.

Mr. Pourcel of Paris gives the following composition for steel rails which he says have stood the test of actual use on French railways better than those containing a smaller percent of Mg.

Carbon .50% to .45%, Mg. .90% to 1.10%, Phos. .08% to .1%, Sulphur .05%, Silicon .02%. He further remarks on the effect of Mg. in steel that, "Mg. without sensibly diminishing the elongation of steel, increases its tenacity & rigidity as well as its power of resisting shocks, it gives to steel the admirable quality of hardness without brittleness". & remarks in conclusion that "I am of opinion that elements like Phos., Si., Sulphur, must be reduced to a minimum, especially Phos., and Sulphur, but I do not put Mg. in the category of ingredients

that are injurious either to the rolling or use of the ~~steel~~ rail. I should give preference to a metal containing Mg. to the amount of 1 p. +

A comparison of these four conclusions with respect to Mg. is instructive.

Authority	C	Ph.	Si.	Mg.
Dr Dudley. (From Dr. Ds. Empts)	.25-.35	.1	.04	.3-.4
Sondrock.	.25-.35	.1	.04	.4-.7
R. W. Hunt	.4	.05	.08	.9
M. Pourcel	.45-.50	.08-.1	.02	.9-1.1.

From these results we see that the greatest difference lies in the amount of Mg. to use. It may be remarked with regard to the 1st two the the data examined did not contain analyses giving as high percent of Mg. as the last two. The general conclusion however remains that Mg in high amount is beneficial to mild steel, such as that used for rails.

But while we have this strong evidence in support of Mg conclusions, there are others who claim that Mg. is injurious to steel. The following is from Jour. Frank. Inst. Aug. '81. "Pure iron and pure carbon make the best steel of all degrees of carburization & for all purposes, Si, Phos. & Mg. in hardening make the make the metal brittle and are injurious in any quit." This is a pretty broad statement considering the no steel has been made, to my

+ Holley, one of our best authorities says, "Mg. is a valuable ingredient in steel."

knowledge containing only iron + Carbon.

Maynard in his work on Iron + Steel says that Mg exerts a pernicious influence. This apparent conflict in authorities is no doubt largely due to the difference in the Chemical composition of the steel from which the conclusions were drawn. To obviate any such misunderstanding it is desirable that the Chemical composition of the steel referred to, be given in connection with the conclusions. For it is evident that Mg may be beneficial under certain conditions + detrimental under other conditions

Sulphur, Phosphorus, Copper, Cobalt, + Nickel.

These are considered together because in many cases it is difficult to separate their effects.

1051-1082. Phos. is apparently more deleterious to high than to low steel. No. 81 with .116 C. is not made brittle by .045 Ph. while 1-82, .070 C. is very brittle with .065 Ph. Will tabulate the data referred to here for convenience (See p. 24)

1081-1084. This sustains the conclusion of Haswell given under Si. that Si. neutralizes to a certain extent the bad effects of Phos.

1081-1086. Large amounts of Phos. in low steel increases strength + decreases ductility.

No.	Sul.	Phos.	Si	Graph.	Carbon.	Mng.	Copper.	Co.	Ni	Elong (per cent)	Tensile Strength (per sq in)
1081	.029	.045	.011	.014	.116	.192	.002	——	——	33.39	51833
1082	.028	.065	.128	.016	.675	.459	.022	——	——	4.59	122400
1084	.007	.179	.219	.008	.144	.563	.013	.075	.055	27.17	54333
1085	.008	.162	.371	.014	.133	.793	.007	.040	.165	22.50	85834
1086	.031	.123	.006	.012	.113	.103	.011	.025	.051	27.00	65000
1087	.041	.125	.128	.007	.348	.404	.252	.149	.102	6.75	78007
1088	.043	.104	.074	.012	.744	.465	.306	.052	.120	1.76	101045
1089	.011	.109	.166	——	.042	.051	.028	.028	.044	27.50	48048
1090	.048	.315	.214	.003	.112	.581	.042	.022	.185	22.11	51500
1092	.066	.099	.016	.012	.314	.525	.306	.054	.078	5.65	79315
1093	.058	.128	.013	.011	.243	.341	.278	.145	.165	15.20	78500
1094	.056	.113	.007	.004	.135	.165	.364	.076	.107	18.06	68667
1096	.038	.092	.170	.012	.375	.685	.210	.050	.115	13.72	111203

1081–1090 Large amounts of Phos. Sulphur, Copper, Co. & Ni. makes a very brittle metal of this mild steel.

1081-1094. We here see the combined effect of Sulphur, Phos. Copper. &c. &c. in mild steel making it so brittle as to be useless.

1082-1085. These confirm the remark made above that Phos. & Sulphur have a more deleterious effect on "big" than on "low" steels. 1085 is a good steel notwithstanding the amount of Phos. present. Its good qualities being apparently due to the large amounts of Mg. and Si. present.

1082-1088 Indicate that large amounts of Copper, Co. & Si. decrease the strength & ductility of steel, It is difficult to determine the effect of each, but we can certainly conclude that Copper, is not beneficial to Steel.

1084-1089. The larger amount of Phos. & Si. in 1084 have given it greater strength. It would appear, the ductility being the same that Si. neutralizes the bad effects of Phos.

1084-1090. Shows plainly that Sulphur & Phos. decrease ductility & also strength.

1085-1084 This comparison shows generally the bad effect of Sulphur, Phos. & Copper on steel.

1085-1092 Shows Sulphur & Copper to be detrimental.

1086-1087 This comparison shows the effect of large amounts of Copper. Co. & Si.

to make steel brittle, an exact comparison cannot be made because of the difference in the amount of carbon present.

1086-1093. Sulphur & Copper increase brittleness.

1086-1094. Shows satisfactorily the effect of Copper, Co. & Si to make steel brittle.

1087, 1092, 1093, 1095. Possess similar properties due to their similar Chem. composition. These steels were Sulphur, Phos. Copper, Co. & Si. absent would be of excellent quality. These substances make them worthless.

1087-1096. Shows the effect of Si (a aid, probably of Mg. also) to increase the strength of the steel & at the same time, neutralize the bad effects of Phos.

1089-1095. Affords a fair comparison for sulphur & Phos. & indicates that Sulphur & Phos. decrease ductility.

Conclusions. Sulphur. As a result of this examination we see that Sulphur increases the brittleness of steel. Very much says "Sulphur is next to Phos. the most injurious, material in steel. It acts similarly to Phos. except that it causes the material to work, with difficulty, while hot" This statement seems to be of more importance to the manufacturer than to the Engineer, because he must get rid of the sulphur in order for the steel to work well. It

gives to steel the property called "red shortness"

Phosphorus

This element is also injurious to steel. It increases the brittleness very much & the strength somewhat. It appears to be more harmful to high steel than to low steel. The presence of Si. seems to counteract its dangerous properties. An examination of Dr Dudley's data shows that Phos. may exist in mild steel up to .1% without making it very brittle & unfit for use. Weyrauch says that "Phos. increases the elastic limit & tensile strength of steel but diminishes its resistance to impact. The steel becomes coarse grained brittle & crystalline." Gruner says "Steel containing above .2% to .25% of Phos. is unfit for use for technical purposes."

Copper. This substance also seems to be injurious to steel increasing the brittleness greatly without any corresponding increase in strength.

Cobalt & Nickel. These substances being associated with large amounts of Copper & Phos. in the steels examined, it is difficult to determine their separate effect. All that I can say is that I have failed to detect any valuable qualities in them.

Chromium.

1077-1078-1079. It is difficult to tell from these experiments, what the effect of Chromium is, 1077 being a poor steel, 1078 a very good steel Chrom. high in both

The numbers, in each of the columns in the table given below indicates the position (1 being highest) which steels containing Chromium occupies out of a total of 17 tests, given in the Chroms Steel Testing Board Vol II pp 5?? & 902. It will be seen that as a rule these steels stand high in the list, & in 9 cases out of the 12 given, the breaking strength per fractured section occupies a higher place than the breaking strength per original section, indicating that the ductility is above the average of these steels.

Break.-Wt Orig. 2½" × 1¾"	Break.-Wt Fract. 2½" × 1¾"	Break.-Wt Orig. 2" × 1¼"	Break.-Wt Fract. 2" × 1¼"	Break.-Wt Orig. Round 1"	Break.-Wt Fract. Round 1"	Break.-Wt Orig. Octagonal ¾"	Break.-Wt Fract. Octagonal ¾"	No	Carbon.	Chrom.	Tensile Strength Orig. Sect.	Tensile Strength Fract. Sect.
								a	1.199	900	116000	161441
(d) 5	4	(b) 9	2	9	1	(f) 7	5	b	.825	.640	97000	153000
7	1	1	4	(e) 6	4	9	1	c	.877	.449	111500	167000
(a) 1	2	2	6	(c) 5	3	5	3	d	1.009	.433	109000	138000
								e	.860	379	158000	144000
								f	.935	.220	114000	142000

Average position for Orig. Sect = 5.5.

" " " Break. " = 3.0.

~~We can only~~ The ductility of these steels with one exception (f), ranges from 12% of orig. length to 18%. The elongation of C. is 18% of original length. This indicates that Chrom. in high steel increases the ductility & also the breaking strength to a less degree.

Antimony. No 1091 is the only analysis containing this substance. The effect seems to be to weaken the steel without increasing its ductility.

On the relation between Si. & Mg. in Steel.

M. Pourcel & Van Bostrand's Eng. Mag. says "The laws of thermo-chemistry equally confirm the opinion to which I some time ago gave utterance that when Si. & Mg. exist together in pig iron or steel they are in a state of chemical combination as Silicide of Mg. at least if in the ratio of Mn : Si. When the amount of Mg. increases the hardening property increases since Mg. possesses the property of dissolving Carbon."

To show the effect of Silicide of Mg. in steel F. Gautier of Paris gives the following experiment, "If over the shavings of steel made with silicon only a current of dry Chlorine is made to pass, we obtain a network of Silicate of iron which preserves the original form of the metal, while in the steel made with Silicid of Mg. all of it is dissolved. The latter steel has a greater degree of homogeneity, each molecule of

metal not being separated from its neighbor by a layer of oxid of iron or of Silicate. This expt. explains how the steel without blow holes with Siliced of Mg. presents a resistance to rupture which makes it almost equal to the better kinds of cast steel drawn under the hammer" & in another place. "The steel made with Siliced of Mg. besides the security which it presents in its homogeneity, preserves when it has been hammered or rolled an increased limit of elasticity with a strong breaking strain & a good elongation". Siliced of Mg. has the formula Si Mn. or the proportion by lots of ~~28~~ 21 : ~~54.8~~ 27.5. The steel made by the Terre Noire works France, contains large amts of Si. & Mg. but the Mg. exists in excess of this ratio. The following is its composition & Phys. properties:-

Carbon .120 %	Limit of Elasticity = 42850 lbs per Sq. in.	The Swedish ordnance Commission
Silicon .234	Breaking Strain = 93160 " " " "	gives the following composition
Mg. .527	Elongation measured on 7.87" = 18.7 %	for cannon. C .35 – .45 %
Sulphur .020	Contraction of area = 48.3 %	Si. .25 – .45 %, Mg .4 – .6 %
Phos. .109.	Break. Strain per contracted Sect. = 180000 lb.	Phos. under .06 %.

Several other good steels are mentioned in the same connection having a similar composition to these. It would seem from this that not only do large amounts of Si. & Mg.

no mild steel produce a superior metal but that the best effect is reach when they exist in a constant ratio. Prop. being the greatest in amount.

Conclusion.

This subject of the relation between the Chem. composition and physical properties of steel opens a broad field for investigation. Combined Chemical analysis and physical tests seem to be the conditions necessary for any great improvement in the quality of our steel in Engineering purposes, - more attention should be given to the chimistry of steel. The idea that pure iron & Carbon will produce the best steel for all purposes seems to me to be contradicted by the results of this investigation, & it seems probable that Silicon & Manganese will be found upon further trial to be more valuable ingredients in steel than hitherto supposed.

The relations existing between the different substances in steel & the nature of their effects upon each other, seems to be complex in the extreme. To find the effect of a substance to vary with its amount and also with the other ingredients present, so that the problem presented is an intricate one.

Not only are we confronted with the problem of finding the effects of different amounts of a substance in the presence of varying amounts of other sub-

stances, but also with that more difficult one of determining the state in which they exist in the metal, whether separate or in Chemical combination with each other. The problem is before us & although much has been done towards its solution, much remains to be done. Advance in engineering construction is hindered by lack of material possessing the required properties more than by anything else, & anything done to improve the quality of our structural materials widens the field of work for the Engineering profession.

— The End —

UNIVERSITY OF ILLINOIS-URBANA
3 0112 086760060